Multi-sensor Remote Sensing in the Nearshore

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LONG-TERM GOALS

The proposed program directly supports the Navy goal of predicting the 4D nearshore environment for amphibious operations that involve surf zone breaching. Our effort specifically involves improving our understanding of the fundamental relationships between nearshore hydrodynamic processes and remote sensing observations of these processes from multiple remote sensors. We utilize this understanding to improve our ability to numerically simulate and, hence, predict the time and space variability of the nearshore environment. The Navy also makes considerable use of remote sensing techniques for littoral mine and obstacle detection, and breaking-induced foam and whitewater can be a significant source of signal clutter for relevant sensing systems. In this regard, the proposed work will also explore the presence of foam and whitewater bubbles as revealed by optical and microwave systems, with the potential to aid in the design and tactical deployment of aerial reconnaissance imaging systems.

OBJECTIVES

The objectives of this project are as follows:

1. Conduct a multi-sensor remote sensing experiment (collaborative with Dr. Bill Plant, Applied Physics Lab, UW-APL and Dr. Rob Holman, COAS, OSU).

2. Development of wave breaking identification algorithms, analysis of remote signals from individual wave rollers

3. Develop and test a deterministic radar scattering model that is applicable to the nearshore.

4. Collaborate in related efforts a) surf zone bubble modeling (Dr. Jim Kirby, U. Delaware) and b) polarimetric remote sensing (AROSS-MSP, Arete Associates).

5. Investigate potential model parameterizations for predicting the coverage of whitewater and foam that will generate clutter at optical wavelengths.

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APPROACH

During the field experiment data was collected using three remote sensors: 1) X-band, HH-pol, marine radar imager, 2) X-band, coherent, dual-polarization radar (RiverRad, UW-APL), and 3) the on-site Argus camera station. This is a unique data set. The RiverRad system operates in staring mode and was also used to calibrate the synoptic marine radar images. The suite of systems allows us to compare the remote signals from breaking and non-breaking waves in both the microwave and optical bands over a large synoptic area of the nearshore zone.

The key individuals in this effort have been the PI along with Patricio Catalan (PhD, Coastal & Ocean Engineering, OSU, Dec. 2008). Bill Plant and Gene Chatham from University of Washington Applied Physics Lab were the owners and operators of the RiverRad system. We have also worked with the Coastal Imaging Lab (Rob Holman and John Stanley) in the collection and processing of the optical data.

Our synoptic combination of both marine radar and video observing systems allows direct comparisons between the two imaging mechanisms and will lead to a better understanding of the strengths and weaknesses of both for nearshore research and observational remote sensing. The main analysis approach has been to develop the joint pdf of the radar and optical signals and to use the joint pdf (JPDF) to clearly identify wave breaking events. The radar signals (from both systems) from these identified events are then analyzed in detail in order to quantify the signals from breaking waves.

Another key aspect of our approach has been the development of a nearshore scattering model for X-band radar. In our scattering formulation the wave roller is modeled as a single layer of water droplets above the underlying wave surface. The backscatter coefficient for this collection of scatterers is determined using the First Order Dense Media Radiative Transfer (DMRT) theory. Under this approach, scattering and absorption of the incident electromagnetic fields are accounted for including coherent and incoherent interactions between particles and also interactions with the media boundaries, in this case, the water surface. Collective scattering effects are included by means of the quasi-crystalline approximation (QCA) to account for the extinction coefficient of the dense media. The method requires a few physical input parameters such as the particle (droplet) size; total volume fraction; a stickiness parameter to account for clustering and the relative electric permittivity and operating microwave frequency. This approach is based on previous work regarding microwave scattering from snow.

Finally, our effort also includes collaboration with Drs. Jim Kirby and Fengyan Shi of the University of Delaware. Under their current ONR project, their objectives are to “develop a model for bubble injection, interaction, and evolution, transport and fate in a complex surfzone environment”. This process is intimately related to the remote sensing observations and the scattering of incident EM energy from the surf zone. We have supplied our optical data from previous laboratory experiments and are working with them on model/data comparisons.

WORK COMPLETED

Actual tasks completed or technical accomplishments.

- Conducted field experiment (MR-SENSO) involving three remote sensors: one Optical (ARGUS III) and two microwave (Marine Radar, X-band, HH,PPI, non-calibrated and RiverRad, X-band, HH/VV/Doppler, calibrated, staring)
- Calibration of marine radar using RiverRad.
- Analysis of MR-SENSO data
  - Characterization of the Probability Density Functions and Joint Probability Density Function associated with optical and marine radar data.
  - Qualitative assessment of the microwave scattering sources associated to different stages of the wave phase (non-breaking, steepening, active breaking, remnant foam)
  - Development and application of a detection method for individual wave breaking events using combined sensor data set.

The above work is summarized in Catalán, 2008; Catalán et al., 2008; and Catalan et al., (manuscript in preparation for *IEEE Trans. Geosci. Remote Sens.*, 2009).

  - Quantification of the backscattered parameters associated to different stages of the wave phase. Relevant parameters under study are the normalized radar cross section and Doppler spectra at both polarizations (HH, VV) and the polarization ratio HH/VV.
  - Comparison of Doppler velocities against celerity estimates.
- Development of nearshore scattering model
  - Actively testing our volumetric scattering model applicable to X-band scattering from the wave breaking roller in the surf zone.
  - Comparison of the volumetric scattering model predictions (cross-sections and polarization ratios) against field data.

The scattering model is presently summarized in Catalán, 2008; and Catalán and Haller (manuscript in preparation for *JGR-Oceans*, 2009).

RESULTS

Through this work we have learned that:

- The active breaking in the wave roller shows similar scattering levels at each polarization (VV, HH), typically at a level around -20 dB with a weak dependency on grazing angle.
- Foam is a relatively weaker scattering source.
- Steepening waves scatter in accordance with the modulation of Bragg scatterers by long waves, with peak VV values typically larger than HH. Peak values, however, are typically at least 20 dB smaller than those of active breaking waves.
- Polarization ratios show a weak differentiation between breaking and non-breaking waves. However, polarization ratio does not appear to be an effective discriminator, as all the sources considered showed instances where the polarization ratio $\geq$ 0 dB.

- Doppler spectra of breaking waves show a distinct broadening, most notably when breaking waves are present, consistent with a population of scatterers traveling at different speeds around the phase speed of the underlying long wave.

Previous identification of breaking waves with remote sensing data has relied essentially upon qualitative measures from optical sensor data. Our work has utilized combined, synchronous signals from optical and microwave sensors. Figure 1 shows the Joint Probability Density Functions from multi-sensor data obtained from different characteristic locations within the surf zone and for different wave conditions. It can be seen that for almost all cases the peak of the JPDF occurs at relatively low video intensities and low backscattered power. This is consistent with the notion of scattering from unbroken waves occurring for a large fraction of the wave phase thus accounting for a larger fraction of the JPDF. When only non breaking waves are present (thus darker video intensities), it is found that the JPDF is concentrated over an axis spanning a relatively narrow range of video intensity bins but spread over a wide range of radar NRCS bins (e.g. Figure 1 b) and c)). This can be explained in terms of a modulation of the signal by the wave slope, which induces a relatively large dynamic range for the NRCS in accordance with the CST. One interesting detail present in for instance in Figure 1 (c) is the presence of events that are very dark (in a video intensity sense) but associated with relatively large scattered power (larger than -30 dB). This means that strong scattering occurs for dark video faces which are caused by the front of steep unbroken waves, another indication of scattering in accordance to Composite Scattering Theory. A similar behavior can be seen in the trough for decaying wave heights (Figure 1h and 1i), but the signal shows a somewhat broader video range making the conclusion less obvious. A secondary axis is also apparent in other cases (e.g. Figure 1a, 1e, 1f). This vertical axis spans a wide range of video intensity bins but a relatively narrow range of backscattered power. This pattern could be explained as remnant foam (which induces a wide video intensity dynamic range) not scattering strongly from microwaves.

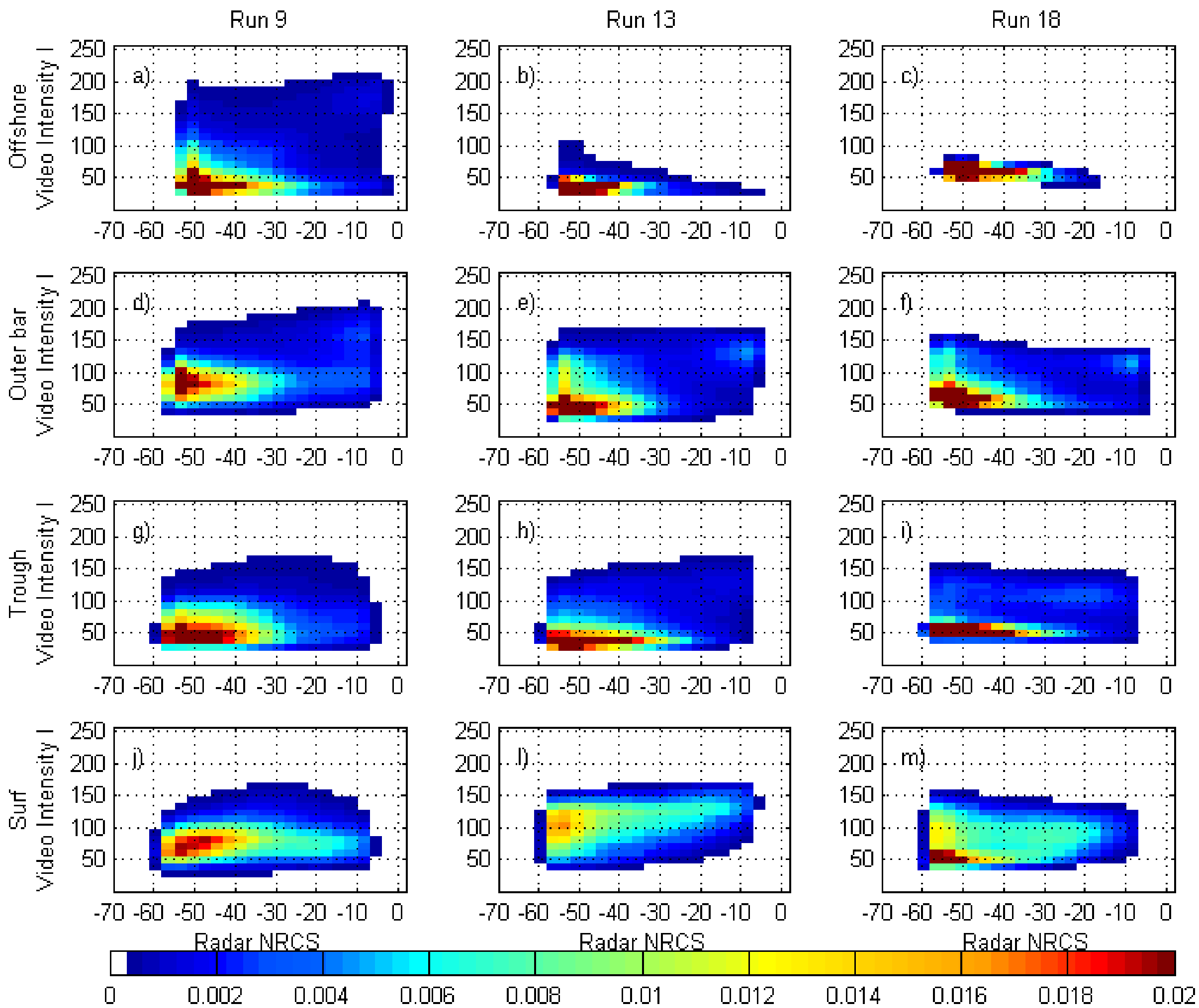

Figure 1: Joint Probability Density function for video (Camera 1) and Marine radar. Columns correspond to Runs 9, 13 and 18, respectively. Rows correspond to zones within the surf.

Using these results from the JPDF analysis, it is then possible to identify individual wave breaking events, and distinguish the active breaking portion from remnant foam, and steep non-breaking waves as shown in Figure 2. The lower left panel shows a color-coded plan view map of different water surface types (active breaking, remnant foam, steep non-broken waves). The lower right panel shows contours demarcating individual wave breaking rollers over a plan view video image.

Once our breaking wave identification algorithm was developed and tested we could use it to analyze in detail the microwave scattering from the breaking portion of the wave only. Catalán (2008) developed a volumetric scattering model applicable to the wave roller and tested it against these data. In the scattering model the upper layers of the roller are considered a two-phase medium of water droplets immersed in air. The model has a few physical parameters as input and no calibration parameters. Under this approach we used a range of physically plausible values for these parameters and compare the model output with measured data. The model results (see Figure 3) show a general good agreement with the data, in particular with regards to the magnitude of the NRCS and its overall

grazing angle dependency. It was shown that only a few combinations of particle diameters and low volume fractions were able to explain the observed scattering. Furthermore, the optimal values of the physical parameters used in the model were within the expected ranges based on the existing laboratory measurements.

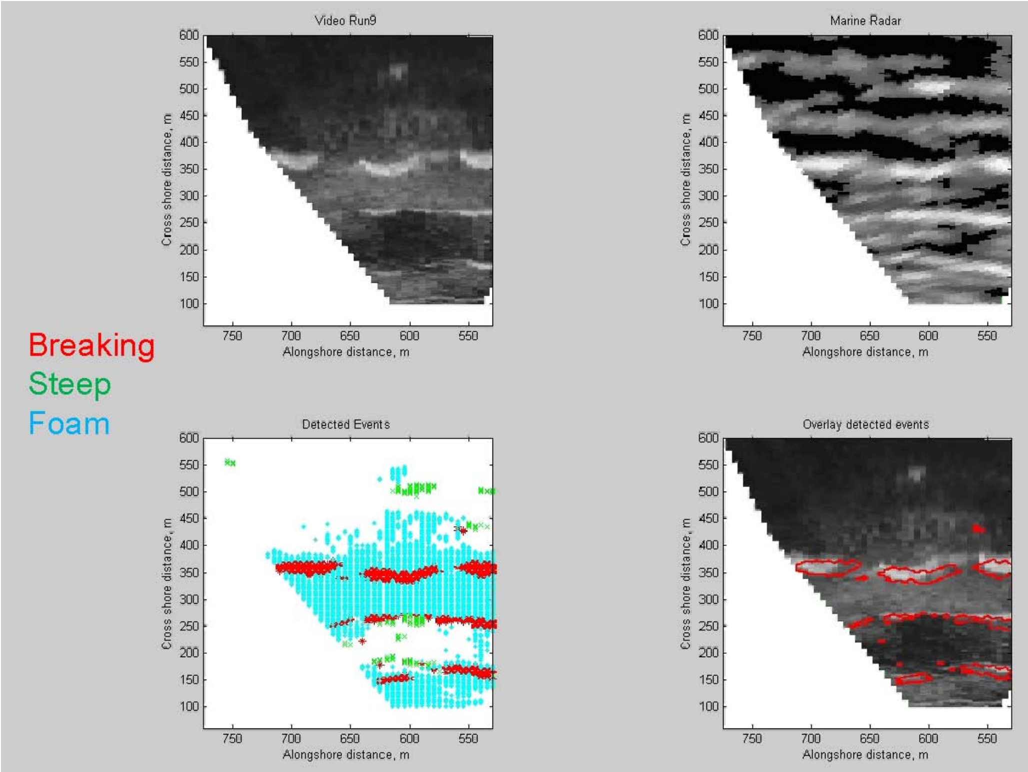

Figure 2: Results from breaking identification algorithm. (top left) Planview video image, (top right) plan view marine radar image, (bottom left) color map of breaking wave roller (red), remnant foam (cyan), and steep non-breaking wave (green), (bottom right) red contours represent individual wave breaking events in video image.

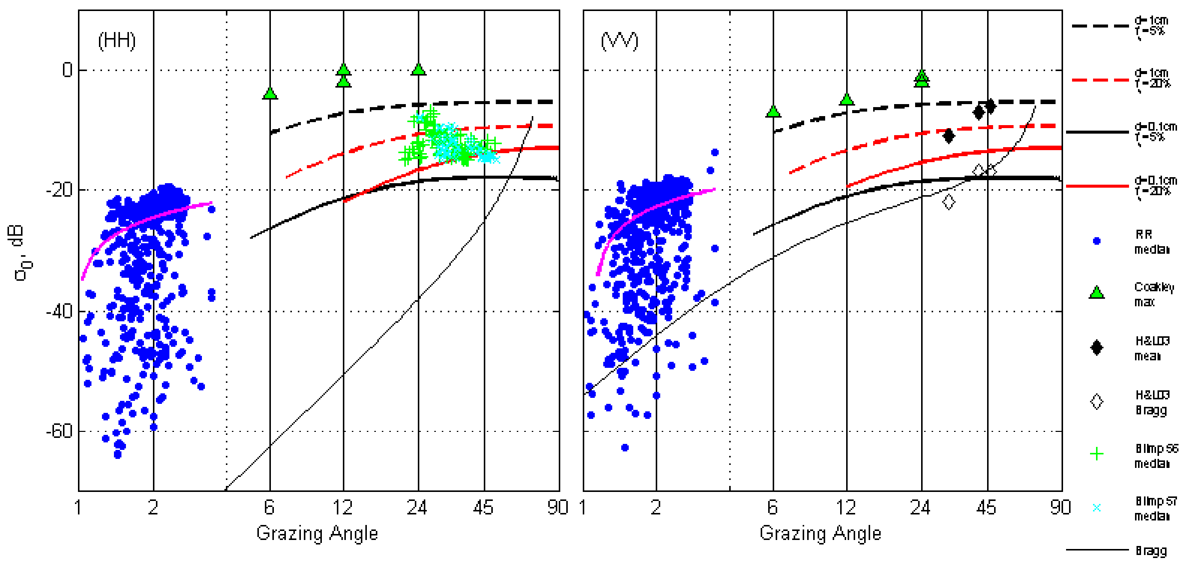

Figure 3: Model data comparison. Model runs correspond to low volume fractions (5% & 10%) for two particle diameters and sticky particles (τ = 0.1). Thin dashed line corresponds to the decay of a Lambertian surface and thin solid lines to Bragg scattering. (+) and (x) correspond to the airship data, triangles to the maximum NRCS from Coakley et al. (2001), and diamonds to the mean from Haller and Lyzenga (2003). Blue dots are the median of the breaking events of the present data (a) HH; (b) VV.

IMPACT/APPLICATIONS

Our effort specifically involves improving our understanding of the fundamental relationships between nearshore hydrodynamic processes and remote sensing observations of these processes from multiple remote sensors. The results herein can be used to improve microwave scattering models for the nearshore ocean. In the future, such models can be formulated in an inverse fashion to estimate surf zone conditions from remote sensing observations. In addition, the initial results from this project suggest that marine radar is an effective tool for filling in the gaps between very nearshore observing systems (video) and larger scale observing systems (such as HF radar, satellites).

RELATED PROJECTS

- *Kirby and Shi, ONR-CG core program* – development of a model for bubble injection, interaction, and evolution, transport and fate in a complex surf zone environment. Their work will inform our bubble distribution model and both efforts can eventually be coupled to form an overall sensor performance model.
- *R. Holman/Coastal Imaging Lab (Coastal Geosciences funding)*—we are active collaborators in remote sensing data analysis and interpretation.
- *Nathaniel Plant, USGS*—we are actively collaborating on wavenumber estimation methods (see Plant et al., 2008) and plan to incorporating regular radar data products into Beach Wizard-lite runs at Duck, NC.

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